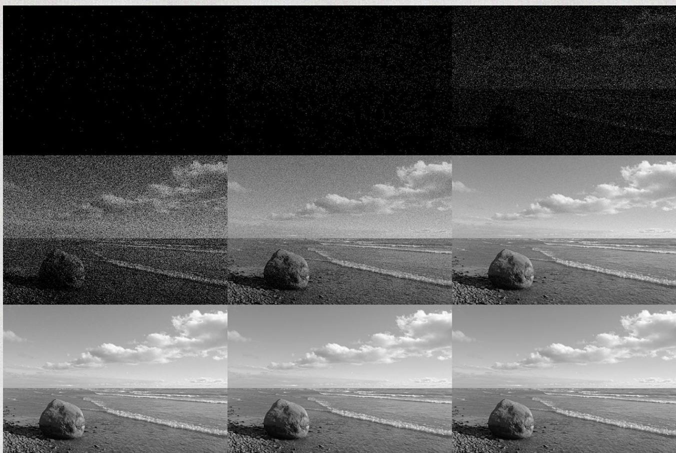
Invertebrate Vision

Jan M Hemmi
School of Biological Sciences

What makes a good eye?

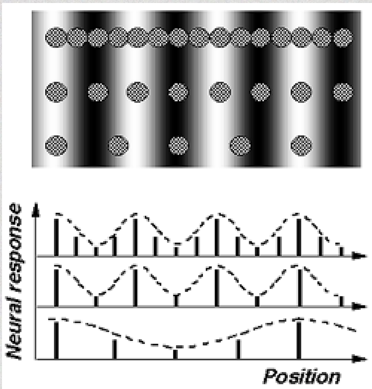
Eye space is limited!

→ light sensitivity & spatial resolution are **traded off** in all eyes! Colour vision, polarisation vision make things worse



Spatial resolution 1: Sampling resolution

The effectiveness of sampling arrays of different densities in reconstructing the viewed grating



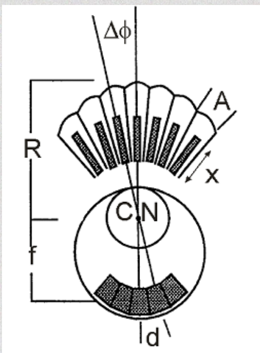
Nyquist limit (2 sensors per stimulus cycle (1 dark and 1 white bar)

Nyquist limit

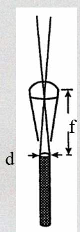
Undersampling leads to aliasing (distortion)

Spatial resolution 1: **Sampling resolution**

Compound eye



Lens eye



$\Delta\rho$ = d/f [radians]
[degrees = 180/π radians]

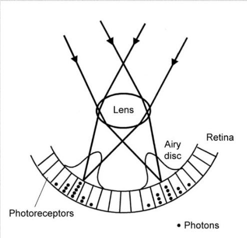
Inter-ommatidial angle $\Delta\phi$: (sampling resolution)
$\Delta\phi = A/R$ (= d/f in lens eye) [radians]

Acceptance angle $\Delta\phi$: (optical resolution)
$\Delta\rho = d/f$ [radians]

with:
A: diameter of the lens
d: diameter of the receptor
f: focal length of the lens
x: length of the receptor (rhabdom)
R: radius of the eye
C: centre of radius
N: nodal point of the lens

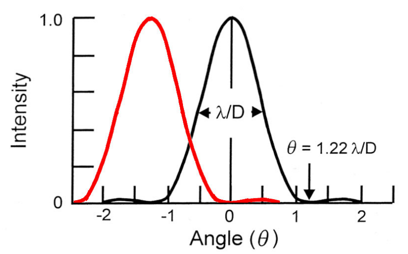
Eyes with **high sampling resolution** are **large**, have small **lenses (A)**, narrow **receptors (d)** and a **long focal length (f)**
(however, small lenses produce blur (see optical resolution - yet anther conflict)

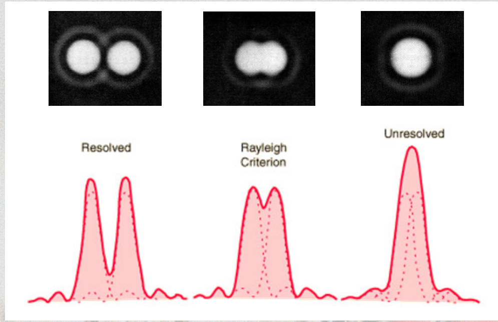
Spatial resolution 2: Optical resolution measures optical quality of the eye (not sampling density)



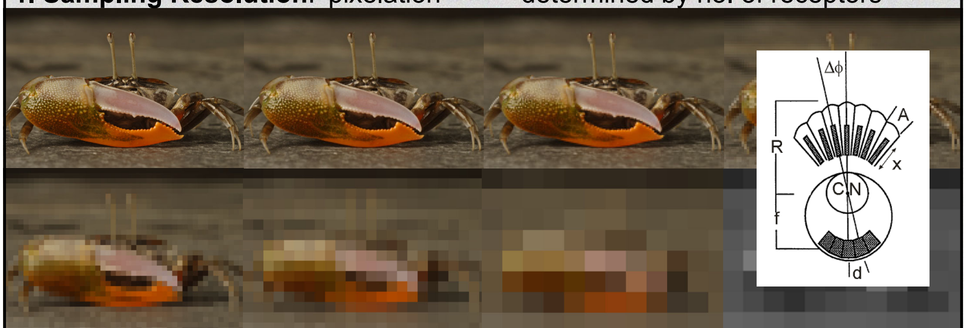
- Rayleigh criterion → minimum separable angle ($\Delta\vartheta$) of the eye
- Wider apertures (D) give better ('optical resolution') - the ability to perceive two points of light as distinct entities (if allowed by sampling resolution)

$$RayleighCriterion: \sin\Delta\theta \approx \Delta\theta = \frac{1.22\cdot\lambda}{D}$$

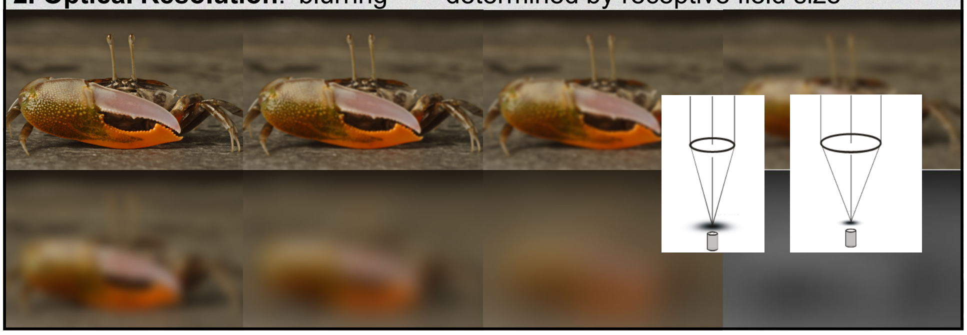




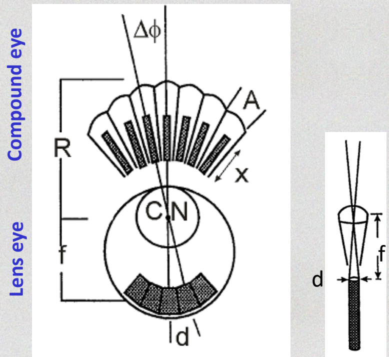
1. Sampling Resolution: 'pixelation' - determined by no. of receptors



2. Optical Resolution: 'blurring' - determined by receptive field size



What determines light sensitivity?



$\Delta\rho$ = d/f [radians]
[degrees = 180/π radians]

The fraction S of photons emitted by a surface which is absorbed by the visual pigment in a photoreceptor depends on:

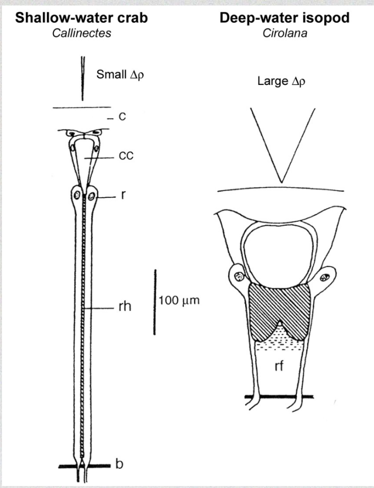
$$S = (\pi/4)^2 A^2 (d/f)^2 \; kx/(2.3 + kx)$$

with:

- **A**: diameter of the lens
- **d**: diameter of the receptor
- **f**: focal length of the lens
- **x**: length of the receptor (rhabdom)
- k: absorption coefficient
- R: radius of compound eye
- C: centre of radius of compound eye
- N: nodal point of the lens in lens eye
- $\Delta\rho$: acceptance angle

Eyes with **high light sensitivity** are **large**, have l**arge lenses (A)**, **long receptors (x)** with **large diameter (d)** and a **short focal length (f)**

Sensitivity *vs* Resolution trade-off!



- **In all eyes there is a trade-off between resolution and sensitivity**
- Wider receptors have bigger $\Delta\rho$ and catch more light, but at the cost of resolving power
  - *Cirolana* $\Delta\rho$ = 47° (0.02 cycles deg^{-1})
  - *Callinectes* $\Delta\rho$ = 2° (0.5 cycles deg^{-1})
  - *Cirolana* ~4000x more sensitive

Main Concepts: What makes a good eye?

- Light sensitivity & spatial resolution are traded off (colour vision too as it requires several types of receptors)

- Large eyes are almost always better:
  - Long focal length (low minimum resolvable angle)
  - Wide aperture
    - reduced diffraction
    - more light

- Eyes with high spatial resolution are large, have large lenses (aperture), narrow receptors and a **long** focal length

- Sensitive eyes are large, have large lenses (aperture), long receptors with large diameter and a **short** focal length